

# Exhibit 14

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# University Physics

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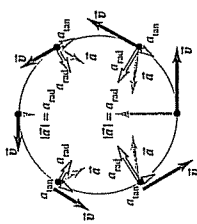
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3-25 A particle moving in a vertical loop, like a roller coaster car, with a varying speed. The radial component of acceleration  $a_{\text{rad}}$  is largest where the speed is greatest (at the bottom of the loop) and smallest where the speed is least (at the top). The tangential component of acceleration  $a_{\text{tan}}$  is in the same direction as  $\vec{v}$  when the particle is speeding up (going downhill) and opposite  $\vec{v}$  when it is slowing down (going uphill).

non-uniform circular motion, Eq. (3-28) still gives the *radial* component of acceleration  $a_{\text{rad}} = v^2/R$ , which is always *perpendicular* to the instantaneous velocity and directed toward the center of the circle. But since the speed  $v$  has different values at different points in the motion, the value of  $a_{\text{rad}}$  is not constant. The radial (centripetal) acceleration is greatest at the point in the circle where the speed is greatest.

In non-uniform circular motion there is also a component of acceleration that is *parallel* to the instantaneous velocity. This is the component  $a_{\text{tan}}$  that we discussed in Section 3-3; here we call this component  $a_{\text{tan}}$  to emphasize that it is *tangent* to the circle. From the discussion at the end of Section 3-3 we see that the tangential component of acceleration  $a_{\text{tan}}$  is equal to the rate of change of speed. Thus

$$a_{\text{rad}} = \frac{v^2}{R} \quad \text{and} \quad a_{\text{tan}} = \frac{d|\vec{v}|}{dt} \quad (\text{non-uniform circular motion}). \quad (3-31)$$

The vector acceleration of a particle moving in a circle with varying speed is the vector sum of the radial and tangential components of accelerations. The tangential component is in the same direction as the velocity if the particle is speeding up, and is in the opposite direction if the particle is slowing down (Fig. 3-25).

In *uniform* circular motion there is no tangential component of acceleration, but the radial component is the magnitude of  $d\vec{v}/dt$ . We have mentioned before that the two quantities  $|d\vec{v}/dt|$  and  $d|\vec{v}|/dt$  are in general *not* equal. In uniform circular motion the first is constant and equal to  $v^2/R$ ; the second is zero.

### 3-6 RELATIVE VELOCITY

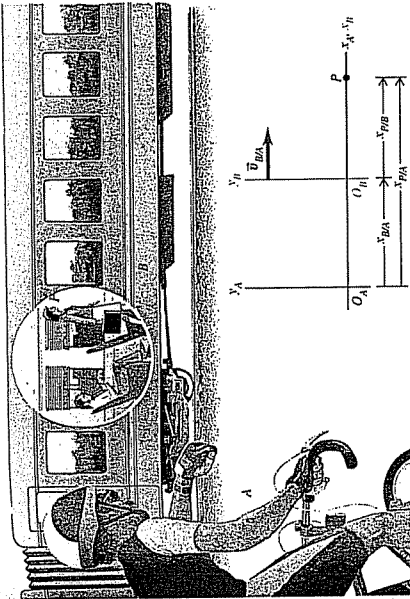
You've no doubt observed how a car that is moving slowly forward appears to be moving backward when you pass it. In general, when two observers measure the velocity of a moving body, they get different results if one observer is moving relative to the other. The velocity seen by a particular observer is called the *velocity relative* to that observer, or simply *relative velocity*. We'll first consider relative velocity along a straight line, then generalize to relative velocity in a plane. Recall that for straight-line (one-dimensional) motion we use the term *velocity* to mean the component of the velocity vector along the line of motion; this can be positive, negative, or zero.

#### RELATIVE VELOCITY IN ONE DIMENSION

A woman walks with a velocity of 1.0 m/s along the aisle of a train that is moving with a velocity of 3.0 m/s (Fig. 3-26a). What is the woman's velocity? It's a simple enough question, but it has no single answer. As seen by a passenger sitting in the train, she is moving at 1.0 m/s. A person on a bicycle standing beside the train sees the woman moving at 1.0 m/s + 3.0 m/s = 4.0 m/s. An observer in another train going in the opposite direction would give still another answer. We have to specify which observer we mean, and we speak of the *velocity relative* to a particular observer. The woman's velocity relative to the train is 1.0 m/s, her velocity relative to the cyclist is 4.0 m/s, and so on. Each observer, equipped in principle with a meter stick and a stopwatch, forms what we call a *frame of reference*. Thus a frame of reference is a coordinate system plus a time scale.

Let's call the cyclist's frame of reference (at rest with respect to the ground)  $A$  and the frame of reference of the moving train  $B$  (Fig. 3-26b). In straight-line motion the position of a point  $P$  relative to frame of reference  $A$  is given by the distance  $x_{PA}$  (the position of  $P$  with respect to  $A$ ), and the position relative to frame  $B$  is given by  $x_{PB}$ . The distance from the origin of  $A$  to the origin of  $B$  (position of  $B$  with respect to  $A$ ) is  $x_{BA}$ . We can see from the figure that

$$x_{PA} = x_{PB} + x_{BA}. \quad (3-32)$$



3-26 (a) A woman walking in a train. (b) At the instant shown, the position of the woman (particle  $P$ ) relative to frame of reference  $A$  is different from her position relative to frame of reference  $B$ .

This says that the total distance from the origin of  $A$  to point  $P$  is the distance from the origin of  $B$  to point  $P$  plus the distance from the origin of  $A$  to the origin of  $B$ .

The velocity of  $P$  relative to frame  $A$ , denoted by  $v_{PA}$ , is the derivative of  $x_{PA}$  with respect to time. The other velocities are similarly obtained. So the time derivative of Eq. (3-32) gives us a relationship among the various velocities:

$$\frac{dx_{PA}}{dt} = \frac{dx_{PB}}{dt} + \frac{dx_{BA}}{dt},$$

or

$$v_{PA} = v_{PB} + v_{BA} \quad (\text{relative velocity along a line}). \quad (3-33)$$

Getting back to the woman on the train,  $A$  is the cyclist's frame of reference,  $B$  is the frame of reference of the train, and point  $P$  represents the woman. Using the above notation, we have

$$v_{PB} = 1.0 \text{ m/s}, \quad v_{BA} = 3.0 \text{ m/s}.$$

From Eq. (3-33) the woman's velocity  $v_{PA}$  relative to the cyclist is

$$v_{PA} = 1.0 \text{ m/s} + 3.0 \text{ m/s} = 4.0 \text{ m/s},$$

as we already knew.

In this example, both velocities are toward the right, and we have implicitly taken this as the positive direction. If the woman walks toward the *left* relative to the train, then  $v_{PB} = -1.0 \text{ m/s}$ , and her velocity relative to the cyclist is 2.0 m/s. The sum in Eq. (3-33) is always an algebraic sum, and any or all of the velocities may be negative.

When the woman looks out the window, the stationary cyclist on the ground appears to her to be moving backward; we can call the cyclist's velocity relative to her  $v_{AP}$ . Clearly, this is just the negative of  $v_{PA}$ . In general, if  $A$  and  $B$  are any two points or frames of reference,

$$v_{AB} = -v_{BA}. \quad (3-34)$$